Simultaneous Generation Expansion Planning and Natural Gas Expansion Planning

A. Nobakht, M.S. Javadi, Z. Manoochehri, S.V. Heidari

Abstract— **Generation Expansion Planning (GEP) is one of the most important issues in long-term power system planning. In from past, investigators noticed to GEP and supply of energy. In power system planning, generation expansion planning is performed for 5-yrears planning horizon or more. There are two main objective functions in GEP. First is the minimization of investment cost and another one is the maximization of reliability. GEP use future likeable engineering economics function, in order to drive certain indicator. Supply of fuel problem is one of the most important of effective factors for result. For this reason, Some times GEP and fuel supply center go hand-in-hand. In this case, construction and operation cost of transmission network add to power system costs. This paper presents the simultaneous generation expansion planning with Natural Gas Expansion Planning (NGEP), as the fuel for generation units.**

Keywords—**Combines Cycle Generation Technology (CCGT), Generation Expansion Planning (GEP), Load Dispatch Planning, Natural Gas Expansion Planning (NGEP)**

I. INTRODUCTION

Energy, Environment, Economy (EEE) is among of basic challenges in electricity industry for the 21st century. Supplying of energy with the minimum levels of possible environment contaminations, costs and the maximum levels of reliability, is an important problem in the industrialized societies. Generation companies (GENCo) has tendency to utilize more efficiency, economy, secure units with the minimum level of pollutant gasses by electricity industry restructuring, privatization -and separation between Generation, Transmission, Distribution parts and to have more competition in these parts. In Power system, GEP include determining capacity that is required for long-term planning horizon, technologies of generation units and construction time interval and location for each unit. GEP problem in restructured and modern power system toward conventional systems is very complex. Generation technologies are classified into two categories:

- Conventional energy (Coal, Oil, Gas, Nuclear, and Hydro)

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- Unconventional and Renewable ones (Solar, Wind, Fuel cells, Biomass, Geothermal, Micro gas-turbines, etc).

One of the methods for improving the efficiency is augmenting these units. In large units, Combines Cycle Generation Technology (CCGT) can decrease the costs. The supply of fuel source for combined cycle units is very important. Because of more and greater efficiency, less pollution and low level of equipment depreciation, competitive electricity market has tendency to utilize natural gas [1].One of the most important characteristics of natural gas is their problem of reserving in comparison with other resources of fossil fuel and due to it identity to consume in consumption places and extraction points or special centers connected to gas supplying network which is very high [2].

Within the Middle East, Iran has the most gas resources and has the second rank in the worldwide ranking after Russia. However, producing of natural gas in Iran compared with resources is very less and has got fourth place of worldwide producing after Russia, US and Canada. This producing is only three percent of worldwide gas production [3].Thus, natural gas can be one of the foresight potentials in future infrastructure expansion of Iran's energy. Demand for natural gas is expected to become more in coming decades, because of rapid growth of electrical energy generation units based-on natural gas (For example combined cycle units as one model of centralized generation units, or micro gas-turbine as one model of Distributed Generation (DG) units).

II. GENERATION EXPANSION PLANNING

Power network consists of equipments and apparatus, which is responsible for Generation, Transmission and secures Distribution of electrical energy for consumers need. There is a need to exact and detailed studies, in order to more expansion and optimized utilization of power networks [4].

Generally, Studies about power system planning can divided into two categories:

- Network Expansion Planning
- Operation Planning

Network Expansion Planning is a long-term planning (Usually for 5-years horizon or more). Operation planning is divided into three parts:

1. Fuel allocation and maintenance scheduling (for one year or more)

2. Unit commitment (Day-Ahead or Weekly-Ahead) And,

3. Load Dispatch Planning (from a few minutes to one hour) [5]

In operation planning, the supposition is that equipment in the network have sufficient adequacy. In this planning, the purpose is the providing secure and economy electrical energy for consumer needs by employing the equipments in the network [6]. If the network has not maintained the demanded adequacy of providing the energy for consumer, Network Expansion Planning (NEP) is necessary for long-term [7]. The main objective of these investigations is the confirming network adequacy by adding new equipment to the network. In other words, in network expansion planning's studies, purposes are determining the type of new equipments, features of equipments and time and the place of equipments installation, so that costs of preparation and installation equipments must be at minimum cost while providing optimal network adequacy. The lack of adequacy of powerhouses in providing of power needed, the lack of quality of transmission network in generating power transmission and power station insufficiency of network in load supplying can lead into lack of adequacy of network in providing electrical energy. In other words determining features of powerhouses and the appropriate time to build new powerhouses and to have new transmission lines and so new power stations, in order to ideal providing energy of consumers needed, are the typically purpose of the network expansion planning's problem.

Problem solving in NEP for a large network is more complex. Hence, because of an optimal solution, the problem must divide into sub-problems. In general, NEP's studies divided into three sub-problems, as:

- Generation Expansion Planning (GEP)
- Transmission Expansion Planning (TEP)
- Substation Expansion Planning (SEP)

It is obvious that whatever the problem divided into smaller sub-problems, solving the problem is easier. Nevertheless, the solution is not an absolute optimal solution. For this reason, in some studies, for obtaining the best and suitable solutions, simultaneous planning of GEP and TEP or simultaneous planning of TEP and SEP, has been studied [9].

From past to now, many studies with different approaches is presented about solving of GEP's problem. Commonly, one multi-objective problem of GEP with different approaches such as minimizing investment cost, environmental issues, reliability, fuel and transmission loss allocation, security and recently investment in generation network expansion by using DG units are presented [6].In this paper, coordination of main infrastructures for supplying of thermal energy is considered. For example, about hydroelectric units, the necessary and sufficient condition is coordination between these units and Down-Stream (DS) units, Up-Stream (US) units and Pumped-Storage (PS) ones.

In the case of decision on construction of a hydroelectric unit, studies of electrical energy generation are not the first priority and in importance ranking, it indicated after supplying of drinking and agriculture water and flood control in some cases. Nevertheless, existing of enough water resources is necessary for dam construction. About construction and coordination of pumped-storage units, conditions are different and somewhat similar to the scenario that considered in this article.Actually, initial infrastructure (water resources for down-stream dam) should be available and accessible to construction of pumped-storage powerhouse. Whatever, the penstock of water transmission will be longer from dam to reservoir; operation and construction will be more expensive. In this case, objective function of problem is minimizing total costs. Technical constraints should be considered this goal.

The construction problem of new thermal powerhouse is very similar to the problem mentioned above and the major difference is that, because of special conditions of problem, should be coordination between natural gas expansion planning and GEP. In this case, the conditions are not established similar to above problem and expansion of each of those cannot independent of another. Therefore, coordination between GEP and NGEP will be performed for long-term planning horizon.

Generally, GEP's problem can express as costs of system:

- Operation costs
- Investment cists

Which operation costs are consist of constant operation costs and variable ones, which indicate the fuel cost, crew payment, maintenance costs and etc. In addition, investment costs include costs of construction for new power plants.

Minimize OF $= \acute{O})$ costs of investment + costs of operation)

The following are some constraints and restrictions of GEP:

- Capacity constraints
- Reliability constraints
- Generating pollutions limitations
- Restriction on amount of special-fuel usage
- Restriction on generating energy of a set of powerplants
- Budget Restriction
- Restriction on capacity of capital

III.COORDINATION OF GEP AND NGEP

The coordination between GEP and Natural Gas Expansion Planning (NGEP) is very important in interconnected power systems. It is necessary that, the coordination of two electrical system and natural gas network formulate together. The purpose of this planning is to minimize investment and operation costs of both systems

simultaneously that are common with each other in some parts of problem [10].
Final optimization can be express as:

$$Min \quad \sum_{t=1}^{T} \frac{1}{(1+\alpha)^{t-1}} [EGEP + OCEE + NGEP + OCNG] \quad (1)$$

Where

á	=	Annual discount rate
EGEP	=	GEP Investment (constant value)
OCEE	=	Operation Cost of GEP (variable value)
NGEP	=	Investment of NGEP (constant value of)
OCNG	=	Operation Cost of Natural Gas network

(variable value)

The formulation of first term of the objective function is written as;

$$EGEP = \sum_{i=1}^{I} \sum_{j=1}^{J} ICE \_Hy_{i,j}^{t} * ST \_Hy_{i,j}^{t} +$$

$$\sum_{i=1}^{I} \sum_{j=1}^{J} ICE \_Th_{i,j}^{t} * ST \_Th_{i,j}^{t} + \quad (2)$$

$$\sum_{m=1}^{M} \sum_{n=1}^{N} ICE \_InE_{m,n}^{t} * ST \_InE_{m.n}^{t}$$

Where

i = Main Bus Indices

j = The number of option of exciting technology for every generation technology

$ICE \_Hy_{i,j}^{t}$ = The capital needed for construction of the j type of hydroelectric unit at Bus i.

Similarity $ICE \_Th_{i,j}^{t}$ is written for construction of thermal units and $ICE \_InE_{m,n}^{t}$ is written for construction of tie line between two points of power system.

$ST \_Hy_{i,j}^{t}$ is hydroelectric unit status that it is a binary variable. If the hydroelectric unit is installed and the possibility of utilization is provided in year t, this value is 1, otherwise $ST \_Hy_{i,j}^{t}$ is 0.

In similar way, $ST \_Th_{i,j}^{t}$ and $ST \_InE_{m.n}^{t}$ have been proposed, for thermal units and tie-lines, respectively. In addition, n and m imply to load centers that are connected to each other by tie-lines.

The formulation of second term of objective function is written as;

$$OCEE = \sum_{i=1}^{I} \sum_{j=1}^{J} \gamma_{i,j}^{t} * Th_{i,j}^{t} + \sum_{i=1}^{I} \delta_{i}^{t} * EED_{i}^{t} \quad (3)$$

Where,

$\gamma_{i,j}^{t} * Th_{i,j}^{t}$ = Production costs of energy for thermal unit with technology j at Bus i, which $\gamma_{i,j}^{t}$ is the cost of generation unit and $Th_{i,j}^{t}$ is the quantity of energy generated by exciting thermal unit in power system.

$\delta_{i}^{t} * EED_{i}^{t}$ = shadow price that is imposed on power system at Bus i (energy can be supplied and without any investment in GEP) which δ_{i}^{t} is the shadow price of generation unit at Bus i.

EED_{i}^{t} = The amount of energy not supplied

The formulation of third term of objective function that presents the investment in gas network is written as;

$$NGEP = \sum_{i=1}^{I} \sum_{j=1}^{J} ICG \_Ex_{i,j}^{t} * ST \_Ex_{i,j}^{t} +$$

$$\sum_{m=1}^{M} \sum_{n=1}^{N} ICG \_InG_{m,n}^{t} * ST \_InG_{m,n}^{t} \quad (4)$$

Where,

$ICG \_Ex_{i,j}^{t}$ = The cost of investment needed for exploration and installation of natural gas extraction equipments by technology j at Bus i.

$ICG \_InG_{m,n}^{t}$ = Amount capital needed for gas transmission by gas pipelines and accessory equipments between two nodes of gas network.

Similar to previous term, two binary variables are indicated for each mentioned variables that are defined as;

$$ST \_Ex_{i,j}^{t} \text{ and } ST \_InG_{m,n}^{t}.$$

Moreover, the formulation of last term of objective function that presents the operation costs of gas network is written as;

$$OCNG = \sum_{i=1}^{I} \sum_{j=1}^{J} \vartheta_{i,j}^{t} * NG_{i,j}^{t} + \sum_{i=1}^{I} \beta_{i}^{t} * NGD_{i}^{t} \quad (5)$$

Where

$\vartheta_{i,j}^{t}$ = Cost of natural gas extraction.

$NG_{i,j}^{t}$ = Cost of natural gas extraction. (The lack of gas supply in consumption center can add a penalty factor, in the same way in electrical energy).

β_i^t $=$ Penalty factor (this amount can be different for each point and in every year).

NGD_i^t $=$ Amount of natural gas, which not supplied.

The constraints related to the units, that we studied, are defined as;

$$\sum_{t=1}^{T} ST\_Hy_{i,j}^t \leq 1 \qquad ; i = 1,....I ; \forall j \in i \qquad (6)$$

$$\sum_{t=1}^{T} ST\_Th_{i,j}^t \leq 1 \qquad ; i = 1,....I ; \forall j \in i \qquad (7)$$

$$\sum_{t=1}^{T} ST\_Ex_{i,j}^t \leq 1 \qquad ; i = 1,....I ; \forall j \in i \qquad (8)$$

For electrical transmission lines construction:

$$\sum_{t=1}^{T} ST\_InE_{m,n}^t \leq 1 \qquad ; m = 1,....M ; n = 1,....N \qquad (9)$$

For natural gas pipelines:

$$\sum_{t=1}^{T} ST\_InG_{m,n}^t \leq 1 \qquad ; m = 1,....M ; n = 1,....N \qquad (10)$$

As mentioned above, the variables in constraints (6) to (10) are binary variables, as:

$$ST,Hy_{i,j}^t ; ST,Th_{i,j}^t ; ST,InE_{m,n}^t ;$$

$$ST,Ex_{i,j}^t ; ST,InG_{m,n}^t \in \{0,1\}$$

These variables represent the applying and the time of applying of equipments needed to power system. Investment costs and constant costs must be considered once a planning. In addition, (1) is included the results of the inflation and amount of interest.

Qualify and adequacy of power system in GEP is expressed as:

$$\sum_{j=1}^{J} Hy_{i,j}^t + \sum_{j=1}^{J} Th_{i,j}^t + EED_i^t \geq \Theta_i^t EL_i^t$$

$$; i = 1,....I ; t = 1,...T \qquad (11)$$

Equation (11), presents the relation between the sum of energy that generate by hydroelectric units ($Hy_{i,j}^t$) and thermal units ($Th_{i,j}^t$), and amount of load. It should be note that Load Duration Curve (LDC), Θ_i^t defines the amount of load at each Bus and time t. If the expected energy not supplied in a part of power system, the mentioned part will be shutdown in that time period. In this case, EED_i^t represents this issue.

There is a similar situation for supplying and adequacy of natural gas resources. Formulation (12) shows this issue, as:

$$\sum_{j=1}^{J} NG_{i,j}^t - \sum_{j=1}^{J} \psi_{i,j}^t * Th_{i,j}^t \geq \Phi_i^t NGL_i^t$$

$$; i = 1,....I ; t = 1,...T \qquad (12)$$

Where

$NG_{i,j}^t$ is amount of natural gas generation in each extraction sites. Total amount of extracted natural gas from gas wells must be greater than amount of demand at each time at load centers. $\psi_{i,j}^t$ is considered in the case of focused technology conversion of thermal units to other forms of technology, and using natural gas as fuel or fuel substitution of natural gas for other forms (gas oil or fuel oil).

As mentioned earlier, operation of power system should be added to GEP's problem, whether for existing units or in the case of added units in planning horizon. These costs for generation units are consisting costs of equipments maintenance, crew costs, installment payment, costs of fuel and for gas natural network, these costs are consisting costs of maintenance of equipments, pumping costs, costs of pressure increase/reduction devices and stations and pipelines operation and maintenance costs.

$$CT\_XX_{Y,Y}^r = \begin{cases} 1 & for \ t \geq r \\ 0 & for \ t < r \end{cases}$$

$$r = The\ Time\ of\ Installing\ Apparatus\ XX \qquad (13)$$

Where

r is the year which equipment is installed.

For existing equipments that are in service, formulation above is written as:

$$CT\_XX_{Y,Y}^r = 1$$

But,

For new equipment, the criterion is the time of the equipments installation in power system and utilizing of them. In the case of electrical energy, because of limitation on supplying of water resources, the amount of hydroelectric energy generation will be limited. Because of specified amount of water withdrawal during each period, lower bound is defined in an annual planning, as:

$$CT\_Hy_{i,j}^r * \Theta_i^t * H_{i,j}^{min}$$

$$\leq Hy_{i,j}^t \leq CT\_Hy_{i,j}^r * \Theta_i^t * H_{i,j}^{max} \qquad (14)$$

It should be note that, the reason of water withdrawal is the supplying of drinking water and Down-Stream dams, also to prevent water overflow (on dam).

LDC is used to determining the upper and lower bound of amount of energy generation by hydroelectric units.

Similarly, this modeling can be expressed for thermal units, as:

$$CT\_Th^r_{i,j} * \Theta^t_i * T^{\min}_{i,j}$$
$$\leq Th^t_{i,j} \leq CT\_Th^r_{i,j} * \Theta^t_i * T^{\max}_{i,j} \tag{15}$$

If there is a transmission line, the limitations are consider on upper and lower bounds for amount of transmitted power between node n and node m.

$$CT\_InE^r_{m,n} * \Theta^t_i * InE^{\min}_{m,n} \leq InE^t_{m,n}$$
$$\leq CT\_InE^r_{m,n} * \Theta^t_i * InE^{\max}_{m,n} \tag{16}$$

Note, $InE^t_{m,n} = InE^t_{n,m}$ in lossless power system.

Amount of load that is not supplied has a minimum level in each generation units. This amount can be determined by reliability standards. According to the diagnosis, security parameters, technical parameters and economic parameters, etc and amount of load that may be not supplied are recognizable in each point of power system, defined as:

$$0 \leq EED^t_i \leq EED^{\max}_i \tag{17}$$

There are some limitations on gas extraction from gas wells, limitation from the standpoint of pressure, limitation in gas well equipments and natural gas storage, and restriction on gas share with other countries. These restrictions and limitations can be moderated the amount of extracted natural gas in each period.

$$CT\_Ex^r_{i,j} * \Phi^t_i * NG^{\min}_{i,j} \leq Ex^t_{i,j}$$
$$\leq CT\_Ex^r_{i,j} * \Phi^t_i * NG^{\max}_{i,j} \tag{18}$$

In addition, there are some limitations for extracted natural gas transmission by gas pipelines.
Formulation (19) represents this issue.

$$CT\_InG^r_{m,n} * \Phi^t_i * InG^{\min}_{m,n} \leq InG^t_{m,n} \leq$$
$$CT\_InG^r_{m,n} * \Phi^t_i * InG^{\max}_{m,n} \tag{19}$$

In a similar way, amount of natural gas that not supplied at any time period and at each point of system, are determined by a series of economic and technical studies. Obviously, each system tends to minimalization of amount of load that be not supplied.

$$0 \leq NGD^t_i \leq NGD^{\max}_i \tag{21}$$

The amount of electrical energy that generated by hydroelectric units and thermal units, should be in allowed limitation. In these conditions, constraints (22) to (32) show that available generation units must supply the amount of load and reserve for each hour. Note, these values must be economic.

$$\sum_{m=1}^{T} ST\_Hy^m_{i,j} * \Theta^t_i * H^{\min}_{i,j} \leq Hy^t_{i,j} \leq$$
$$\sum_{m=1}^{T} ST\_Hy^m_{i,j} * \Theta^t_i * H^{\max}_{i,j} \tag{22}$$

$$\sum_{m=1}^{T} ST\_Th^m_{i,j} * \Theta^t_i * T^{\min}_{i,j} \leq Th^t_{i,j} \leq$$
$$\sum_{m=1}^{T} ST\_Th^m_{i,j} * \Theta^t_i * T^{\max}_{i,j} \tag{23}$$

IV. SIMULATION

To illustrate our approach, the purposed method is applied to a 6-Bus test network with total capacity of 560 MW which 10 transmission lines supply three load centers. Transmission capacity of each line is 160 MW [11].

In this simulation, GEP is considered for 10-years planning horizon. Annual load growth and interest rate are estimated of %10 and %15 for each year, respectively. Three types of technologies are suggested for generation units, that depending on the time required for their construction, 3, 5 and 6 years is needed. Capacity of these units are 100 MW, 150 MW and 250 MW, respectively and the generation cost for each units are estimated at 75, 73 and 70 $/MWh respectively and installation costs are estimated at 1, 1.3 and 2 million dollars for each units, respectively. In this paper, heat rate for natural gas is 13.8 MBTU/MWh and minimum thermal value of natural gas is 26.8 m³/MBTU that by conversion to Mm³/MMWh (Million Cubic Meters/Million MWh) this value will be attained 0.00370 Mm³/MMWh (or 370 m³/MWh). The generation cost of electrical energy for unit with capacity of 100 MW will be 66.6 $/MWh. If one suppose that the cost of transmission is 304 $/MWh, the net income is going to 70 $/MWh. With considering the other costs such as, maintenance costs, depreciation costs and crew costs, the final cost is estimated at 75$/MWh. Actually, in this paper revenue of units for per MWh charge will be 8.4 $/MWh (75-66.6 = 8.4). Note, the congestion rent and expense can go to minimum value by management in operation. Final costs are 73 $/MWh and 70 $/MWh for units with a capacity of 150 MW and 250 MW, respectively. Obviously, using of a larger unit causes investment costs will be more and operation costs will be less [12].

In GEP, the optimum value of generation units is described, as following:

- A unit with capacity of 100 MW has been purposed at Bus 3, simultaneous with construction of pressure reduction station 6 in third-year.
- In fifth-year, a unit with capacity of 150 MW will be constructed at Bus 6 that its fuel can be provided from station 2.
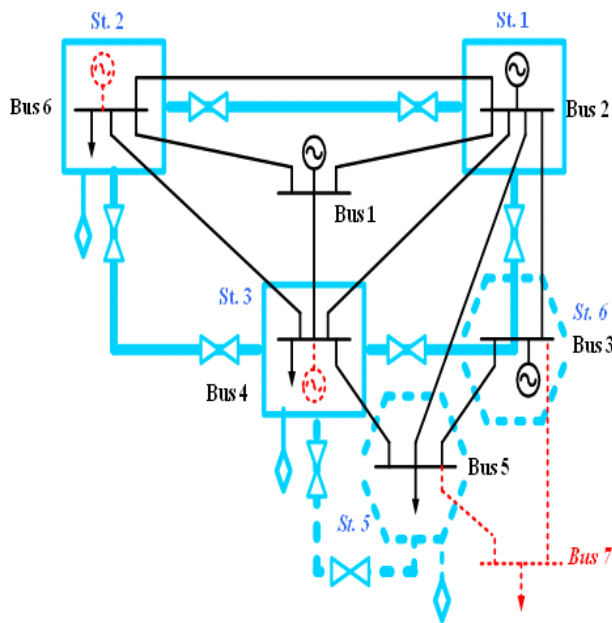
Fig.1 generation expansion planning and gas network at Bus6

- Economic deliberation and three transmission lines represent that the best option for expansion is the construction and utilization of a unit with capacity of 250 MW at Bus 4. Via considering equal times for construction of units with capacity of 150 MW and 250 MW (5 years), this option will be the best and expansion plan will limit at Bus 6. However, because of the costs of load that not supplied (in fifth-year) and other econometrics parameters, a unit with capacity of 150 MW must construct and utilize in network, inevitably. Fig.1 shows the generation expansion planning and gas network at Bus 6.

In this planning, because of increasing gas consumption at Bus5, will construct a radial station.

Because of load growth at Bus7, (build an industrial factory) it is necessary to construct an electrical meshed network through Bus3 and Bus5 at seventh-year and eighth-year, respectively (because of shout down costs of industrial load).Little distance from Bus5 to Buses 3, 6 and 2 is justifiable due to little costs and time of construction.

In addition, Bus5 is a secure Bus in communication and existing available links in it, too.If the new industrial zone is intended to construct a DG unit or diesel generator.

This zone can make a decision to natural gas expansion planning at next years or buy gas oil, install and utilize diesel generator. In addition, this new zone will need to construction cost of a pressure reduction station and gas pipelines and feasibility study of electrical energy with network and obtaining revenue in peak load and intermediate load conditions.

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